GROUNDWATER DEPLETION AND COPING STRATEGIES OF FARMING COMMUNITIES IN HARD ROCK AREAS OF SOUTHERN PENINSULAR INDIA

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This study examines the impact and potential opportunities of groundwater irrigation on rural farm households. Focusing on the size and pattern of the groundwater economy in selected villages located in the hard rock areas of Karnataka, India, the paper argues that the groundwater economy is shrinking due to the depletion of this precious resource. Although investment in groundwater irrigation provides wealth-creating opportunities in addition to helping to meet consumption needs, more often than not, the ongoing need to drill for new wells to counteract severe depletion problems cuts into the investment returns and ultimately affects the pool of assets. Farmers have adopted several coping strategies to overcome the negative externalities of groundwater depletion in this region. Groundwater irrigation has the potential to be a more productive instrument for sustainable rural development in fragile eco-regions. But, in order to make investment in this area a viable option for rural livelihood enhancement, certain policy, institutional factors and other issues need to be addressed.

JEL Classification: O12, Q12, Q15, Q25.

Key words: Groundwater, farming communities, irrigation, economic development, India.

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I. INTRODUCTION

The ongoing degradation of resources is a formidable challenge that affects both poverty and ecosystem resilience. Land degradation and water scarcity are key factors limiting food production and wealth generation for poor people, and further degradation and scarcity are projected (Sharma and others, 2005). The expanding world population accompanied by higher levels of poverty is exerting greater pressure on natural resources, leading to gradual resource degradation. Poor farmers, globally, tend to be associated with marginal lands and low yields (Rockström and others, 2003). As a consequence, these farmers have a limited livelihood status and face various socio-economic and environmental constraints. Development in Asia is at stake due to the stagnation and declining resource use productivity, alarming degradation of natural resources, particularly soil and water, and declining land-man ratio (Wani and others, 2001). Farmers are operating under these precarious conditions to meet increasing food demand. The hard rock areas are not an exception to this trend. The growing demand for foodgrains to supply the rapidly increasing population has put natural resources, such as land and water, under severe stress in these areas. Thus, efforts have been ramped up to increase the net irrigated area to enhance the productivity of land and water.

Some regions have experienced agricultural prosperity due to water resource endowments. The complimentary nature of water and other inputs has boosted public investment in surface irrigation in these regions in order to achieve food security. However, in the absence of public investment due to the lack of surface irrigation sources, individual households have been compelled to take initiatives to invest in groundwater irrigation to produce foodgrains to sustain rural livelihoods (Dhawan, 1995). Of late, investment in groundwater development has picked due to available institutional credit and the supply of electricity remaining steady despite priced fluctuations. However, on the other hand, pressure from the growing population and the effects of economic development, including urbanization, industrialization and mechanization of agricultural activities, have reduced the supply of available water (Kumar and others, 2008). This has resulted in resource scarcity, and has pushed farming into marginal areas, especially in the hard rock areas where there is no assured source of perennial irrigation. Several experiences have already shown that increasing groundwater scarcity in these areas has undermined the agriculture activities (Janakarajan, 1993; Nagaraj, 1994; Nagaraj and others, 1999; Nagaraj and Chandrakanth, 1995; Nagaraj and others, 1994; Chandrkanth and Arun, 1997).

The purpose of this paper is to assess the impact of groundwater depletion on rural livelihoods in the hard rock areas of southern peninsular India. By analysing the size and pattern of the groundwater economy, the paper examines the potential

threats from groundwater depletion and coping strategies to withstand short-term shocks.

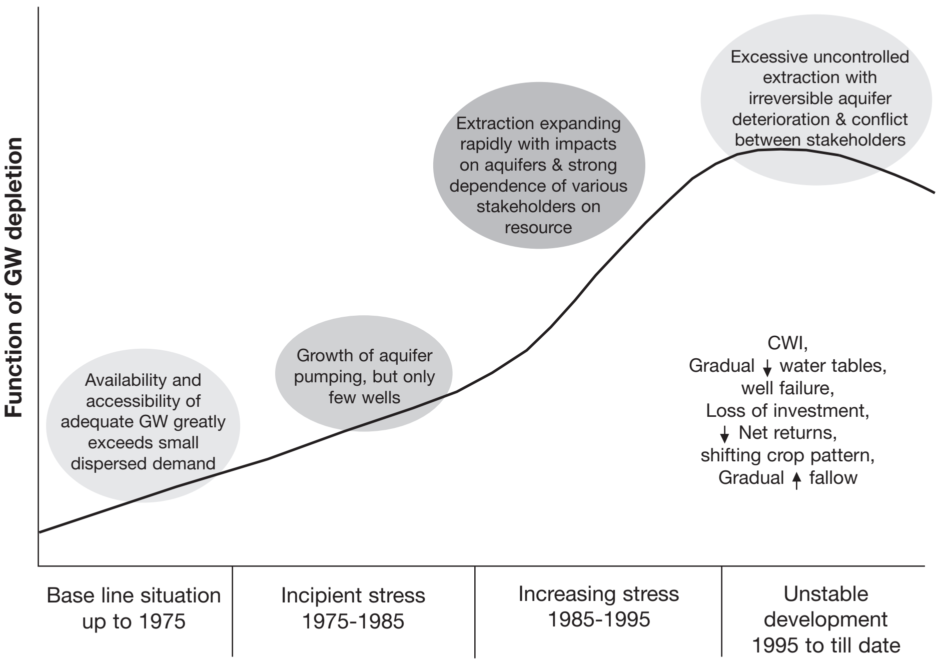
II. CONCEPTUAL FRAMEWORK

During the past few decades, great strides were made in agricultural technologies aimed at enhancing productivity. This, in turn, ensured food security. However, in regions where essential inputs, such as irrigation were harder to implement, public investment in these technologies were not forthcoming, limiting the ability to achieve sustainable agriculture. The hard rock areas fell into this category. The spread of groundwater irrigation, which began in the 1950s, went through four distinct phases of groundwater development, mainly due to institutional and technological changes. Later, due to aquifer development, the groundwater scenario changed drastically, leading to the over-exploitation of groundwater. Figure 1, which presents the four phases of groundwater development, provides a clearer picture of the extent of groundwater exploitation in the hard rock areas. In the baseline situation, commercial crops were not cultivated and demand for water was relatively low. Consequently, there was an overall balance between the extraction and recharge of groundwater (Nagaraj and others, 1999). Demand for water increased in line with the Green Revolution,[1] which put greater focus on agriculture in order to increase food production. Initially, surface irrigation was highlighted, with more public funds being allocated to irrigation projects to meet increased demand for irrigation water. However, ecologically fragile regions that lack surface water sources needed to rely on private investment to augment irrigated areas through groundwater development. As a result, groundwater exploitation was prevalent in these areas (see figure 1). In the fourth phase, groundwater-based agriculture shifted to commercial crops and induced higher demand for reliable water sources. Groundwater from deep surface bore wells paved the way for reliable and equitable exploitation of water to sustain these crops. In this process, the yield of dug wells and dug-cum-bore wells (DCBWs) declined drastically while investments in deep bore wells increased manifold. The depth of the wells also increased the cost of operation and maintenance of pump sets. Rapid changes have occurred during the past four decades in the groundwater irrigation economy of the hard rock areas. Some of the more significant ones include: the increased number of wells; the greater depth of the wells; failure of wells; the disappearance of traditional lifts; higher cost per unit of water extracted; high density of wells per unit of area without considering spacing criteria; a greater area devoted to commercial crops; increased costs associated with improvements of wells; and a shift

[1] The Green revolution refers to a series of initiatives, occurring between the 1940s and 1970s, that increased agriculture production around the world.

to dry land agriculture in some cases (Janakarajan, 1993; Nagaraj, 1994; Chandrakanth and Arun, 1997; Shivakumaraswamy and Chandrakanth, 1997; Nagaraj and others, 2003; Janakarajan and Moench, 2006). In addition, the changes raised tensions among stakeholders over who had customary rights to the groundwater (see Rao, 2006). As a consequence of these factors, groundwater sustainability in the hard rock areas was put in a precarious condition.

Figure 1. Stages of groundwater development in hard rock areas



Source: Author's compilation.

Many experts argue that no single factor provides the solution for most of these problems. However, current literature owes much to Boserup (1965, 1990), who believed that population pressure was the driving force behind the adoption of more advanced forms of agricultural technology, beginning with the abandonment of shifting cultivation and fallowing. While Boserup focused on increases in labour-land ratios, subsequent writers have considered the role of fertilizer, irrigation and other inputs. (Kanhert and Levine, 1989). Dhawan (1995) believed that the most predominate fact was groundwater irrigation, which he said improved productivity by more than 2.5 per cent compared to dry land agriculture. In addition, two other noted basic advantages

of groundwater irrigation over surface water irrigation are that it is relatively less sensitive to rainfall variability and enables users to obtain water more or less on demand. These advantages have led to more secure agricultural planning and lower levels of risk, which have consequently encouraged investment in the inputs necessary to utilize new agricultural technologies. Several studies have argued the importance of groundwater with regard to irrigation has helped encourage complementary investments in inputs such as fertilizers, pesticides, high yielding varieties (HYVs), which, in turn, has increased crop yields. (Kanhert and Levine, 1989).

However, there are diverging views among researchers on the pathways of agricultural change in response to increasing scarcity of productive resources, such as land and water. According to Boserup (1965), increased subsistence demand encouraged land-saving and labour-intensive technical change, which raised production per unit of land, in which resource scarcity was a major driving force for intensification of agriculture. The theory of induced technical and institutional innovation formulated by Hayami and Ruttan (1985) supported this view. The diminishing returns to labour would be offset and degrade the resource base as efforts to boost earnings would entail exploiting more resources. On the other hand, neo-Malthusians rejected the positive autonomous role of population growth in the process of agricultural change and strongly argued that population growth, far from being a positive driving force, was a principal agent leading to a spiral of negative consequences, such as environmental degradation and lack of food security, in developing countries (Meadows and others, 1972, 1992; Hardin, 1995; Cleaver and Schreiber, 1994).

Similarly, the lack of efforts towards implementing management responses to groundwater problems reflected a combination of technical, social, behavioural and organizational limitations that were weakening the balanced use of water for development. Such limitations were often compounded by the growth of competing demands and social conflict over access to the resource and the manner in which it was being used. However, this process of development also entailed considerable damage to the physical environment, including degradation and depletion of groundwater resources and unsustainable use of land and water resources. Hence, the issue of groundwater and livelihood consonance today is essentially not technical but managerial. The problems arising from the above process have their roots in economics, sociology, political issues, ecology and the environment. Therefore, the effects, especially those pertaining to groundwater resources, have interrelationships with multiple issues.

III. MATERIALS AND METHODS

The objective of this paper is to analyse the implications of groundwater depletion on rural livelihoods, and to assess the coping strategies to deal with them. For this purpose, we interviewed farmers in the central dry zone of Karnataka, India from the taluks[2] of Madhugiri and Hosadurga. Based on a classification system listed by the Department of Mines and Geology of the government of Karnataka, the status of the groundwater in Madhugiri was classified as over-exploited, while in Hosadurga, it was considered to be safe. The classifications are the following: if the proportion of groundwater extraction from the groundwater recharge is above 100 per cent, the area is over-exploited; between 85 and 100 per cent, it is categorized as critical; between 65 and 85 per cent, it is categorized as semi-critical; and below 65 per cent, it is considered as safe area. The fact that the two regions fell into categories in opposite ends of the spectrum implies that groundwater extraction has multi-dimensional effects on its use level within an agro-climatic zone.

The sample for this paper consists of 225 farmers selected from different categories based on their degree of dependency on groundwater-based agriculture. Using participatory rural appraisal (PRA), wells (both functional and non-functional), well depth, distance between wells, farm size and farmers' names were mapped in each village. From the map, a sample of farmers, who had irrigation wells, which were densely placed, was drawn from nine villages in the two taluks. The information gathered includes, among other things, a socio-economic profile, details of irrigation wells, information on access to groundwater irrigation and information about agricultural inputs and outputs. The outputs were based on harvest figures reported in kilograms or quintals by farmers and converted to weight measures at the nearest market place where the farmers' sold their goods. The primary survey was conducted from August to December 2007.

IV. GROUNDWATER IRRIGATION: BOON OR BANE?

According to Kumar and others, 2008, most of the states in India were largely agrarian, and rural livelihoods were heavily dependent on the degree of agricultural development. This trend held true for the hard rock areas as well. These areas were fairly advanced in terms of the adoption of new crop technologies and mechanization of agriculture, making irrigation the most critical component to sustain rural livelihoods through high-yield crops. Irrigation played an important role in enhancing crop productivity by making multicrop and multiseason cultivation possible. Thus, the livelihood impact of irrigation in the hard rock areas indicated increasing economic

[2] A Taluk is a subdivision of a district; a group of several villages organized for revenue purposes.

resistance to the shocks in the household economy. Groundwater irrigation affected rural livelihoods in many different ways. Access to groundwater enhanced the yields and created demand for associated products and services while reducing the risk of crop failure. For farmers, assured irrigation was the prerequisite for increasing agricultural productivity.

The above condition deteriorated when resource scarcity, as a result of groundwater overdraft, led to crop failures. The losses were, in fact, even more severe than in areas that had not built irrigation systems. This was because economies in irrigated areas had shifted to more intensive production techniques, requiring higher inputs, such as fertilizer, and associated cash, labour and other forms of capital investment. Basically, groundwater overdraft posed a severe threat to agricultural production, and consequently, the overall economic development of a region became uncertain.

Land and water are the most influential factors in maintaining livelihoods in agrarian economies as well as in determining household livelihood strategies. The study villages used in this paper were drought-prone in which climate was a major factor contributing to this regular occurrence and the ongoing desertification process. Invariably, groundwater depletion and quality issues became major problems in these villages, forcing the farmers to change their agricultural practices to adjust to the varying climate and their natural resource endowments (table 1).

Table 1. Key characteristics of the study villages

	Hosadurga			
Particulars	**Adrikatte**	**Heggere**	**Huralihalli**	**Marabagatta**
Caste composition	Lingayat, Ediga	Lingayat, Kurba	Lingayat	Lingayat
Livelihood options	Agriculture, livestock, floor mill, petty business	Agriculture, livestock, petty business	Agriculture, livestock	Agriculture, livestock
Climatic conditions	Semi-arid	Semi-arid	Semi-arid	Semi-arid
Resource condition (water, land and soil)	Moderate soil fertility; high groundwater depletion; groundwater quality problem	Moderate soil fertility; moderate groundwater depletion; groundwater quality problem	Moderate soil fertility; high groundwater depletion; groundwater quality problem	Moderate soil fertility; high groundwater depletion; groundwater quality problem

Table 1. *(continued)*

Hosadurga				
Particulars	**Adrikatte**	**Heggere**	**Huralihalli**	**Marabagatta**
Others	Sefl-help groups, milk cooperative society	Self-help groups, milk cooperative society	Self-help groups	Self-help groups, milk cooperative society

Madhugiri					
Particulars	**Chandragiri**	**D.V. Halli**	**Garani**	**Kambadahalli**	**Madenahalli**
Caste composition	Vokkaliga, Lingayat, Kuruba	Vokkaliga, Muslims, Ediga, Kuruba	Vokkaliga, Lingayat, Ediga, Kuruba	Vokkaliga	Vokkaliga, Reddy, Nayaka
Livelihood options	Agriculture, livestock	Agriculture, livestock	Agriculture, livestock	Agriculture, livestock	Agriculture, dairy activity
Climatic conditions	Semi-arid	Semi-arid	Semi-arid	Semi-arid	Semi-arid
Resource condition (water, land and soil)	Moderate soil fertility; high groundwater depletion; groundwater quality problem	Moderate soil fertility; high groundwater depletion; groundwater quality problem	Poor to moderate soil fertility; high groundwater depletion; groundwater quality problem	Moderate soil fertility; high groundwater depletion; groundwater quality problem	Poor to moderate soil fertility; high groundwater depletion; groundwater quality problem
Others	Self-help groups, milk cooperative society	Self-help groups, milk cooperative society	Self-help groups, milk cooperative society	Self-help groups	Self-help groups, milk cooperative society

Source: Primary survey.

Size of groundwater economy

An estimate of the size of the groundwater economy in each region was made based on a primary survey of gross private returns from crops grown in the study villages. The total value of agricultural output generated through well irrigation was estimated to be 4,071,885 Indian rupees (₨) in Hosadurga and ₨ 3,693,844 in Madhugiri during 2006-2007. Table 2 shows that coconut accounted for a major share of the groundwater economy in Hosadurga, where it had become a profitable crop because of the effective market demand and other agronomic factors. The table

indicates that the share of coconut in the overall size of the farm economy was 87.14 per cent in Hosadurga, while in Madhugiri, it was only 9.60 per cent. In Madhugiri, paddy comprised the largest share of total crops grown in the region at 31.5 per cent, followed by areca nut (17 per cent) and groundnut (15.5 per cent). Paddy is also a staple food crop in Madhugiri and farmers there tend to allot a small portion of their plot to cultivate it for their household needs. Importantly, areca nut, was the number two crop in the region as cultivation of it began during the early stages of the groundwater economy.[3] But in Hosadurga, because of late planting resulting in less production than their potential, the returns had been low compared to Madhugiri. During the field study, we learned that groundnut was a profitable crop, given the conditions of water scarcity. A majority of the farmers interviewed complained about crop failure during 2006-2007 due to bad rainfall and climatic conditions. However,

Table 2. Annual size of groundwater economy in study areas (in Rs.)

Crops	HOSADURGA		MADHUGIRI	
	Value (Rs.)	Share (%)	Value (Rs.)	Share (%)
Areca nut	8 933	0.22	629 415	17.04
Coconut	3 548 073	87.14	354 602	9.60
Groundnut	107 133	2.63	573 041	15.51
Paddy	165 131	4.06	1 164 762	31.53
Ragi	16 365	0.40	238 890	6.47
Vegetables	196 212	4.82	59 386	1.61
Flower	NC	–	37 822	1.02
Jowar	NC	–	174 009	4.71
Mulbury	NC	–	65 254	1.77
Onion	NC	–	31 717	0.86
Others	30 038	0.74	364 946	9.88
Total	**4 071 885**		**3 693 844**	

Source: Primary survey.

Note: NC stands for no cultivation.

[3] Chandragiri – a village in Madhugiri taluk – had been bearing the brunt of well failure since 2003. The village was once an areca nut and paddy granary, but had become a dry area due to water scarcity. Nearly 25 acres of areca plantations became dry in the village. Farmers, who realized the problem, adopted water-saving methods, such as drip irrigation. However, by the time these methods were adopted, the entire crop area became dry. This resulted in heavy debate among farmers themselves about interlinking rivers to preserve water bodies such as tanks and facilitate aquifer recharge in the area. Unfortunately, nothing happened.

table 2 indicates that there were significant variations in the size of the groundwater economy across the study villages.

Table 3 shows that the annual size of the groundwater economy varied across villages in both the areas. In Hosadurga, Adrikatte topped the table at Rs 1,171,496 followed by Marabagatta (Rs 1,052,409), Huralihalli (Rs 688,792) and Heggere (Rs 124,036). In Adrikatte, coconut and vegetables were the major crops that accounted for a major share of income. In Madhugiri, the size of the groundwater economy varied from Rs 1,065,306 in Garani where a variety of crops were grown to Rs 340,418 in Madenahalli, which was vulnerable to agricultural activities due to water scarcity. In general, based on our findings, it can be concluded that the size of the groundwater economy in the hard rock areas depended on cropping patterns, availability of water and climatic conditions.

Dealing with water scarcity

Groundwater irrigation had affected livelihood sources by cutting into income generated from farm and non-farm activities as a whole. This study focused on areas where long-term groundwater overdraft was compounded by cumulative well interference. In these areas, people tended to adopt new techniques as water became less available. However, the over-exploitation of the groundwater led to the deterioration of the living standards of the rural farm households in many different ways. The more visible impact of groundwater depletion was on the income status of households and food security. To counteract this, the following steps were taken 1) farmers attempted to diversify income sources away from water-dependent, agricultural livelihood; 2) increased access to water was sought by drilling deeper bore wells; and 3) households borrowed from informal sources to cover the increasing cost of irrigation such as bore wells and other accessories.

Table 4 shows the proportion of income generated from irrigated agriculture to the income generated from all sources. It also indicates that well irrigation contributed a major share to the total income of all the farmers across all the villages, with a greater proportion going to the medium and large farmers. In the case of marginal and small farmers, the proportion varied from village to village. As the area under irrigation was limited, small and marginal farmers had to depend on some non-farm activities, such as construction, driving and security work in urban areas to supplement their income.

The contribution of irrigated agriculture to livelihood security was significant in both the areas. However, the degree of the contribution varied from village to village and across size classes, depending on resource availability and the opportunity to utilize the resources. Small and marginal farmers were not in a position to experiment

Table 3. Annual size of the groundwater economy in study villages (in Rs)

Crops	Adrikatte	Heggere	Huralihalli	Marabagatta	Chandragiri	D.V. Halli	Garani	Kambadahalli	Madenahalli
Areca nut	368	8 565	NC	NC	494 513	93 345	50	6 385	35 122
Coconut	933 256	NC	688 792	890 873	72 485	71 720	182 137	28 260	NC
Groundnut	51 135	NC	NC	55 998	NC	247 842	95 779	153 635	75 785
Floriculture	NC	NC	NC	NC	NC	35 722	NC	2 100	NC
Jowar	NC	NC	NC	NC	NC	3 482	105 659	15 228	49 640
Mulberry	NC	NC	NC	NC	NC	3 507	5 030	56 717	NC
Onion	NC	NC	NC	NC	NC	19 685	NC	NC	12 032
Paddy	37 175	78 218	NC	49 738	125 898	386 567	310 777	267 011	74 509
Ragi	NC	NC	NC	9 150	5 368	62 642	73 420	85 146	12 314
Vegetables	149 562	7 215	NC	46 650	NC	22 159	12 303	5 076	19 849
Others	NC	30 038	NC	NC	NC	23 628	280 151	NC	61 167
Total	**1 171 496**	**124 036**	**688 792**	**1 052 409**	**698 264**	**970 299**	**1 065 306**	**619 558**	**340 418**

Source: Primary survey.

Note: NC stands for no crop cultivation.

Table 4. Proportion of income based on well irrigation to other income

Villages	Marginal	Small	Medium	Large	Overall
			HOSADURGA		
Adrikatte (N = 24)	–	0.93	0.70	0.87	0.80
Heggere (N = 35)	0.98	0.37	0.90	0.87	0.67
Huralihalli (N = 12)	–	0.97	0.98	0.94	0.94
Marabagatta (N = 31)	–	0.92	0.81	0.88	0.86
All Villages [N = 102]	0.98	0.65	0.79	0.90	0.80
			MADHUGIRI		
Chandragiri (N = 29)	0.61	0.68	–	0.93	0.73
D.V. Halli (N = 21)	0.54	0.36	0.47	–	0.39
Garani (N = 38)	–	0.42	0.50	0.59	0.45
Kambadahalli (N = 15)	0.95	0.67	0.64	0.38	0.48
Madenahalli (N = 20)	–	0.51	0.55	–	0.53
All Villages [N = 123]	0.61	0.45	0.53	0.54	0.49

Source: Primary survey.

with new technology or improved agricultural practices due to their small land holding and poor capital base. In spite of having access to agricultural credit, subsidized electricity, seeds and fertilizer, small and marginal farmers were still living in poor conditions. In some areas, where wells had dried up, the inhabitants migrated to nearby urban centres and cities. The sustainability of communities in rural areas are in doubt if the conditions mentioned above persist for an extended period of time.

Table 5. Livelihood index of irrigated agriculture

Area	Farm income	Livestock income	Other income	Total income	Livelihood index
HOSADURGA	1 222 435	183 024	126 550	1 532 009	0.91
MADHUGIRI	602 443	154 196	479 100	1 235 739	0.61

Source: Author compilation from primary data.

It is clear from table 5 that the average household income from crop production and livestock was much higher in Hosadurga. However, other sources of income, either directly or indirectly, dependent on irrigation were higher in Madhugiri because of the above mentioned reasons. The major reason supporting irrigation's

greater impact in Hosadurga was the availability of more land for cultivation. This gave farmers leeway in managing their crops with less water intensive and high water efficient crops such as coconut and areca nut. It is important to mention that while the average land area under cultivation was much higher, the net returns were also higher. This was also due to less variability in resource availability, such as land and water. In contrast, in Madhugiri, due to high variability in water resource availability, agriculture production was hampered. It was also adversely affected by small landholdings and changing cropping patterns.

Since agriculture plays a major role in enhancing rural livelihood, the livelihood index[4] suggests that there was greater scope for increasing the capacity of the farm households to withstand shocks. This not only helps us understand the composition of income in the livelihood system but also indicates how much impact irrigation has on the farm households. Meanwhile, on a regional basis, Hosadurga benefited more from irrigated agriculture.

In Hosadurga, farmers had access to water without much problem as this area faced comparatively less scarcity. Reliability of groundwater was high and water was used to maximize areas under irrigated production with wealth-creating water efficient crops. In addition, larger holdings and land consolidation made mechanized farming easy. For instance, drip irrigation was feasible in areas where perennial as well as plantation crops were grown, and tractors could be used for cultivation in the larger areas.

In contrast, climatic conditions and land characteristics enabled Madhugiri farmers to intensify land use by cultivating water-intensive vegetables and paddy, staple crops, which were consumed by farmers themselves on a daily basis. In addition, due to water scarcity, multiseason cultivation and multicropping declined in this region. Of note, the level of mechanization of farming was low in Madhugiri compared to Hosadurga due to the lack of land consolidation, which inhibited the use of new technology, such as tractors and drip and sprinkler irrigation. This obviously was a constraint in achieving higher farm productivity as well as water use efficiency.

[4] The livelihood index is a technique for assessing the role of agriculture in enhancing livelihood.

V. INCREASING COST: A REAL BANE OF GROUNDWATER IRRIGATION

Cost and returns

The rise in annual irrigation costs could be partly attributed to the scarcity of groundwater. A comparison of the annual cost and returns from groundwater irrigation between the two regions indicated that the irrigation cost contributed to the major difference in the cost of cultivation, which was higher by 35 per cent in Madhugiri (table 6). Higher repair and maintenance costs comprised a major portion of the irrigation cost. As water levels declined, the capacity of pump sets to lift water from deeper depth needed to be increased. However, due to voltage fluctuations, the frequent burning of pumps occurred, inflicting heavy losses on farmers. As a result, there was a variation in terms of net returns; the net income was negative in both the regions, but Hosadurga was marginally better off compared to Madhugiri. Of note, the impact of irregular electricity supply on the cost of groundwater irrigation was severe in the hard rock areas.[5] The irregular supply was not only the result of scarcity of electricity but also due to groundwater extraction. Due to irregular electricity supply, a majority of farmers used automatic pumping systems to reduce labour costs. The use of an automatic pumping system not only results in wastage of electricity but affects the groundwater supply. Consequently, the use of this system increased environmental costs as well as economic costs to the society in general and to individual farmers, in particular. Although gross income per well and per acre in Madhugiri and Hosadurga were comparable, considerable differences between the two regions existed in terms of net income (table 6).

The cost of groundwater per acre-inch corresponded with the water used in both the areas. The average cost per acre-inch of water was nearly one-and-a-half times higher for small farmers in Hosadurga, while in Madhugiri, this amount was in the reverse order. For large farmers, their higher gross irrigated areas (GIA) tended to require more water, resulting in a high cost per acre-inch of water. The results were statistically significant except for net return per farm and per acre of GIA, signifying the need to improve resource use efficiency in irrigated agriculture.

An evaluation of the costs associated with irrigated agriculture against the returns revealed that groundwater irrigation was not impressive, particularly for small farmers, because of the serious overdraft problem. The net return in both the areas

5 In all the study villages, electricity supply was irregular and varied between 5-6 hours/day. The fluctuation of electricity supply lead to burning of motors, hence, more cost to replace motors. On the other hand, the full supply (three-phase) was during night time due to which they have to experience many difficulties such as snake bites leading to heavy expenditure on health measures.

Table 6. Annual cost and returns from well irrigation per farm

Particulars	HOSADURGA		MADHUGIRI	
	Per well	Per acre	Per well	Per acre
Volume of water extracted from well (M^3)	5 992	1 919	7 039	2 231
Volume of water extracted from well (acre-inch)[a]	58	19	68	21
Human+bullock labour (Rs)	6 691 (23)	2 143	8 150 (20)	2 584
Fertilizer cost (Rs)	7 028 (24)	2 251	7 462 (18)	2 365
Other variable cost (Rs)	521 (2)	167	2 699 (7)	855
Opportunity cost of capital @ 9 per cent[b]	1 282 (4)	410	1 648 (4)	522
Irrigation cost (Rs)	13 851 (47)	901	21 410 (52)	1 784
Total cost (Rs)	29 373 (100)	5 872	41 369 (100)	8 110
Gross income (Rs)	29 331	9 394	33 037	10 474
Net income (Rs)	-42	3 522	-8 332	2 364

Source: Primary survey.

Notes: Figures in parentheses indicate percentage to the total cost.

[a] One acre-inch = 102.79 M^3.

[b] Interest rate during the fourth quarter of 2007 was considered to indicate the realistic opportunity cost of capital as field work was carried out during this time.

showed that the small farmers were in a precarious situation while the large farmers benefited from groundwater irrigation because of their large holdings and rich resource base that could withstand short-term shocks. However, any positive changes in resource use efficiency could have improved the benefit-cost ratio.

Debt-asset ratio (DAR)

The decline in private returns from groundwater-based agriculture was the best indicator of how groundwater was being exploited in the hard rock areas. As groundwater resources declined, farmers tended to invest in well irrigation by borrowing funds. However, for the most part, they did not get the expected returns from the investment due to the high rate of well failure and low yield rate, and in the process were saddled with high interest rate payments and accumulated debts. In order to understand the vulnerability and pressure on households resulting from groundwater overdraft, the magnitude of the household debt was examined. The burden of debt on a household was assessed by comparing debt-asset ratios.[6] The

[6] Debt-asset ratio is defined as the ratio between total debt outstanding of a household and the fixed and durable assets the household owns.

major sources of finance for acquiring irrigation assets in the study area were informal money lenders, friends and relatives. The farmers in Madhugiri tended to resort to these informal sources of finance due to restrictions placed by the National Bank for Agricultural and Rural Development (NABARD),[7] on farmers in getting access to institutional credit due to groundwater overexploitation. As a result, over a period of time, debt had become an integral part of the rural peasant household in these areas. In fact, borrowing had not been a recent phenomenon but had crossed the acceptable limits a few years prior due to the start of declining water levels and frequent well failures caused by cumulative well interference. These debt woes had been driving long-term migration in the peasant community. Seasonal migration, meanwhile, had also been occurring, especially in Madhugiri due to the area's limited livelihood opportunities.

The extent of a household's indebtedness explained the real financial implications of resource depletion in the study area. The proportion of households reporting outstanding debt ranged between 38.2 per cent in Hosadurga to nearly 49 per cent in Madhugiri (table 7). Among the different landholding groups, marginal and small farmers were the worst affected based on the debt ratio in both the areas. But, the magnitude was high in Madhugiri where groundwater reached a critical level and investment was needed to restore resources. One reason for the high incidence of debt was that cumulative well interference resulted in a high incidence of well failures, prompting farmers to take advantage of institutional crop loans that were made available through primary agricultural co-operatives to finance work to deepen the well and purchase pump sets and storage tanks.

The average debt per household was reported to be highest in Madhugiri (₨ 60,475) compared to Hosadurga (₨ 44,974). A different pattern in average debt per household existed among the different classes of farmers. This, in a way, explained the financial needs of the households to restore resource endowments and maintain intergenerational equity.

The debt-asset ratio (DAR) indicates the ability of a household to tackle the indebtedness problem. That is, the higher the debt-asset ratio, the lower the repayment capacity and vice versa. In other words, a high DAR reflects low creditworthiness because household income must be diverted to cover interest payments to keep capital debt unchanged. Given the high rate of interest, (between 24 per cent and 36 per cent per annum) for informal borrowing during the time of the study, there was an inverse relationship between DAR and creditworthiness. Due to

[7] NABARD facilitates natural resource management based livelihoods by integrating technology and credit. Its objectives are to enhance livelihoods and quality of life of the rural community through improved resource conditions.

Table 7. Extent of household indebtedness in the study area

Size class	Percentage of indebted households	Loan outstanding (Rs/household)	Loan-repayment ratio (LAR)	Total asset value (Rs/household)	Debt-asset ratio (DAR)
HOSADURGA	38.2	44 974	0.5	137 439	0.32
Marginal	50.0	31 000	0.6	98 880	0.31
Small	32.4	23 500	0.6	100 229	0.23
Medium	38.5	37 200	0.5	138 288	0.27
Large	41.4	78 750	0.3	197 448	0.39
MADHUGIRI	48.8	60 475	0.6	154 613	0.39
Marginal	73.3	54 818	0.5	70 466	0.77
Small	50.7	61 040	0.5	130 637	0.47
Medium	36.4	83 875	0.5	202 000	0.42
Large	30.8	24 000	0.8	306 153	0.08

Source: Primary survey.

the high DAR, the farm households in the regions were not able to make productive investments that would have ultimately helped repay the loans. Instead, funds had to be used to repay the interest on the loan and not the loan amount. The farm households, consequently, got stuck in a deep trap, which made them vulnerable to an increasing debt ratio.

The difference in the average DAR between Madhugiri and Hosadurga was marginal (table 7). However, this ratio varied greatly among size classes between the two areas. The debt-asset ratio was low among different size classes in Hosadurga compared to Madhugiri. This clearly reflected the disadvantage of the problem of resource scarcity. Though farmers in Hosadurga also reported a high incidence of debts, their position was comfortable when compared to farmers in Madhugiri, who had to deal with the brunt of cumulative well interference. In Madhugiri, the DARs were inversely related to farm size, indicating that the debt burden fell more on smaller farmers compared to medium and large farmers, while the picture was diverse in Hosadurga. The increasing intensity of groundwater over-exploitation posed several challenges to farming communities in these areas. Therefore, several strategies were adopted to mitigate groundwater overdraft.

VI. THREE PILLARS OF LIVELIHOOD STRATEGIES

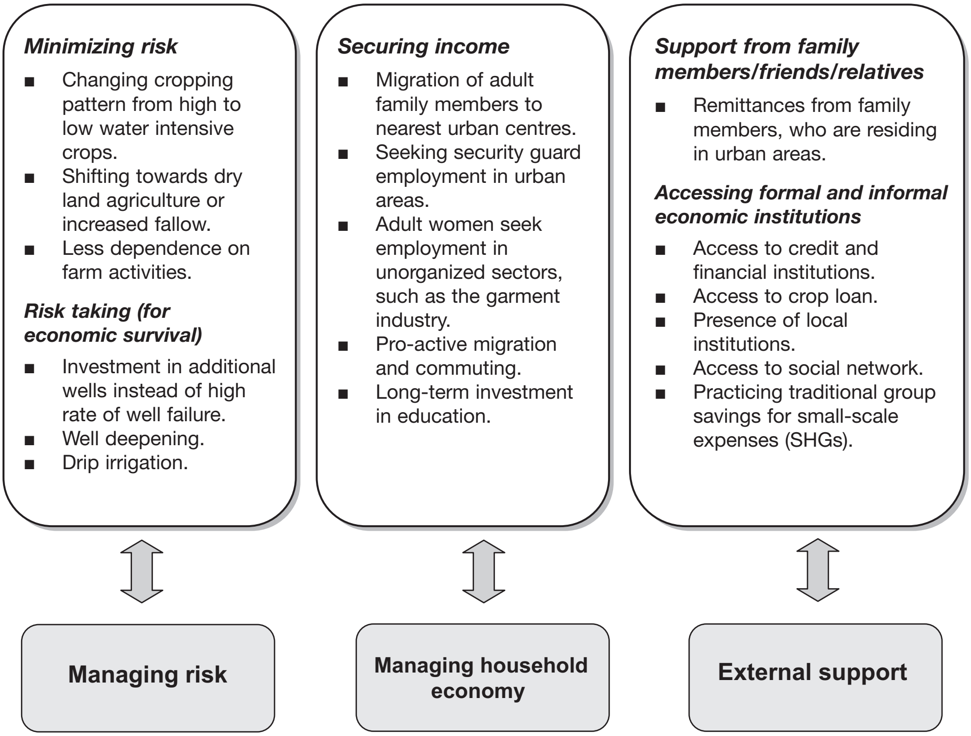
What does the above problem imply for responses to the emerging groundwater problems? While exploration of all the implications is well beyond the scope of this paper, a few problems stand out: (1) the emerging phenomenon indicates that interference, change and adaptation are inherently interlinked processes, and that periods of interference should be recognized as opportunities as well as times of crises. The most natural time of change in an agricultural economy based on intensive groundwater use is during the crisis of water scarcity. During this time, creative destruction is likely to occur and livelihood, economic and political systems will be forced to adapt; (2) the shift away from the rain-fed system of agriculture to groundwater irrigation in this region increased productivity, reduced vulnerability and encouraged the development of systems that depend on secure water supplies when water supply reliability declines. Therefore, appropriate mechanisms need to be put in place over time to maintain the system; and (3) the situation suggests that a livelihood founded primarily on groundwater irrigation is likely to be much less resilient when the resource fails than one based on diverse agricultural and non-agricultural activities. Similarly, the diversification within agricultural livelihood systems' resilience in terms of crop varieties and allied agricultural activities are important.

Several strategies to mitigate groundwater overdraft problems have evolved, including some that have developed over an extended period of time. To be more specific, a combination of factors have enabled most of the villages to diversify their livelihood activities into ones that are less water-dependent. The livelihood strategies involved three pillars in mitigating the groundwater depletion problems. The three pillar model includes managing risk, managing household economy and external support (Korf and others, 2001). Livelihood strategies of households in the hard rock areas comprise a portfolio of short-term coping and long-term adapting strategies. The study shows that changing a pattern of mobility and successful diversification into less water dependent activities are a key response of people to adjust to a risk-prone environment (figure 3).

Minimizing risk

Our study shows that among the different strategies households utilized to minimize their personal risks, changing the cropping pattern from high to low water intensive crops was high on the list. Nearly one third of the respondents adopted a changing cropping pattern as a coping strategy in Madhugiri while in Hosadurga, the number comprised one fourth of the respondents. This strategy, which involved shifting to low water intensive crops such as coconut, ragi, groundnut and sunflower, was mainly implemented in response to insufficient water supply. Small farmers, as

Figure 3. Three pillars of livelihood strategies



Source: Adopted from Korf and others, 2001.

a group, were the most prone to shift crop patterns due to their inability to cope with the progressive lowering of water tables. Importantly, there were noticeable differences between farmers in Hosadurga and Madhugiri on how they carried out the strategy. For instance, initially, paddy was the major water intensive crop in both regions. However, as a result of the unabated water scarcity problem, the cropping pattern shifted from paddy to low water intensive crops, such as coconut, in Hosadurga, while ragi and groundnut were the dominant dry land crops adopted by farmers in Madhugiri. Also of note, the study found that fallow land was increasing at high rate in Madhugiri.

The reasons behind the shifting cropping pattern varied between the two regions but the dominant factors in both areas were inadequate water supply and well failure. Of the farmers who shifted their cropping pattern, nearly 80 per cent in Hosadurga and about 58 per cent in Madhugiri indicated that inadequate water supply was the main reason behind the shift (table 8). Interestingly, well failure, was second

Table 8. Details of changing cropping pattern in the study area

HOSADURGA		MADHUGIRI
	Total no. of farmers	
102		123
	No. of farmers with shifting cropping pattern as coping mechanism	
30 (29.4)		40 (32.5)
	Major shift from	
Paddy = 28		Paddy = 21
Others = 02		Mulberry = 19
	Major shift to	
Coconut = 16		Groundnut = 05
Ragi = 04		Ragi = 18
Vegetables = 03		Sunflower = 05
		Others = 04
Fallow = 07		Fallow = 08

Reasons for shifting cropping pattern (%)	Hosadurga	Madhugiri
Cope with reduced yield	3.3	2.5
Due to electricity short supply	10.0	0.0
Well failure	3.3	20.0
Inadequate well water	80.0	57.5
Crops use less water	3.3	2.5
Others	0.0	15.0

Year-wise shift

HOSADURGA		**MADHUGIRI**	
Prior to 2000	**2001 onwards**	**Prior to 2000**	**2001 onwards**
11 (36.7)	19 (63.3)	19 (47.5)	21 (52.5)

Source: Primary survey.

Note: Figures in parentheses indicate percentages.

most common reason for the shift among farmers in Madhugiri, comprising 20 per cent of the total. The shift in the cropping pattern as noted on an annual basis reveals that the severity of water scarcity increased after 2000. During this time, well interference problems emerged as a serious issue because of variability in rainfall and heavy demand for water. Consequently, a high rate of well failure as well as crop failure due to water scarcity occurred. This was one of the main reasons for the shift in the cropping pattern during this period in both the regions.

Risk taking for economic survival

Investment in additional wells to address the high rate of well failure had been increasing at an alarming rate among study villages. Most of the large farmers opted to construct additional wells when the previous ones failed while more than 75 per cent of the small and marginal farmers invested in additional wells in Madhugiri. This clearly indicates that small farmers were in a precarious position due to the declining water tables. The large farmers in Madhugiri also adopted a strategy to transfer water from distant places to the areca nut garden.[8] Therefore, in addition to drilling additional wells, water transfer from distant places had become a burden on the household economy. This involved monetary risks, physical labour and dependence on access to tractors to transfer the water. The field observation during data collection confirmed that most of the small farmers who had pursued the additional well strategy, mobilized capital from their friends and relatives.[9] However, it must be noted that, in general, even though drilling additional wells helps farmers recover from the immediate shocks of water scarcity, it is not an effective coping mechanism as it puts pressure on the resource base in the long run.

Securing income

Migration is one of the core strategies of farm households to gain access to outside labour markets and sources of non-farm income. However, in the study area, this occurred due to severe overdraft of groundwater. Migration, in a true sense, had become a core strategy to secure income lost as a result of groundwater overdraft. Household that invested in efforts to find non-agricultural work for at least one key member in an urban area, were doing well in terms of coping with the problems. The strategy involved a long-term investment in education. In most of the cases, when crop failure occurred, the income generated by household members working in urban areas became a critical buffer for livelihood or the source of capital for recovery or investment for those still living in the rural areas. However, in a few instances, migration was on a short-term seasonal basis in order to take advantage of specific local work opportunities. Most of the participants in this type of work were rural

[8] A few farmers in Chandragiri village had been transferring water from the neighbouring villages since 2002 to protect areca nut plantations. Initially, a group of households pooled resources and hired a tractor to transfer water on a daily basis. They installed a pipeline to obtain water. This coping mechanism was adopted by large farmers who could afford to do so. However, it could not be sustained due to several reasons, including that it was not economical.

[9] The other sources of capital investment on well irrigation with a consequence were sale of assets such as livestock, trees, such as eucalyptus and teak, and land. Gold was also mortgaged. Of note, several small and marginal farmers used the crop loan for the repayment of old loans.

illiterate unskilled labourers. They were mainly employed to do short-term seasonal daily wage construction work, or by security firms. The core point here is that mobility is a key factor enabling diversification and in many cases, it serves as a short-term response to the problems caused by groundwater overdraft. From the survey, we learned that members of the younger generation from rural areas, who are uneducated/semi-skilled, tended to migrate to urban centres to support their families.

Credit requirements is one of the critical components of adaptation. The progressive lowering of the water table resulted in a high rate of well failure. Farmers, consequently, opted to construct additional wells, an action that requires a huge investment. To finance the investment, many farmers relied on informal sources as funding from institutional sources were not forthcoming for several reasons. This was particularly the case in Madhugiri where, as mentioned earlier, NABARD had imposed restrictions on institutional finance to restrict groundwater over-exploitation. However, in Hosadurga, the proportion of households who obtained loans from institutional sources was high. This was clearly a reflection of the inequity that exists in access to credit facilities.

Local financial institutions, such as self-help groups (SHGs), had operations in almost all the study villages, and played an important role in helping farmers access short-term loans. In fact, based on the results of the survey, SHGs were one of the major sources of finance for investments by farmers in irrigation assets. One of the main advantages of borrowing from SHGs, despite their high interest rates, was that it enabled borrowers to avoid the time-consuming procedures entailed from obtaining loans from institutional lenders.

The occupational structure is one of the key strategies for diversification. Although the groundwater overdraft problem had been severe, agriculture remained the major occupation for all respondents, irrespective of landholdings. This clearly points out the importance of agriculture in the rural livelihood system. However, other non-farm occupations had been pursued by respondents to the survey, an indication that diversification through occupational structure already existed. Children from families that had invested in their education succeeded in getting appropriate jobs. But, nevertheless, agriculture remained the primary source of income for the entire family because they could not find salaried jobs for all members of the family. Access to the market and transport facilities is another essential factor for diversification. All of the surveyed villages had good infrastructure facilities, such as road and transport. Therefore, most of the rural households had easy access to an outlet for selling their goods.

In summary, a majority of the farmers in the study areas adopted coping strategies to mitigate the problem of groundwater overdraft, many of which had been developed over an extensive period of time. Among them, migration was a short-term strategy the majority of unskilled persons used to cope with seasonal agricultural distress due to groundwater scarcity. In the spring harvest and summer seasons when groundwater was not plentiful enough to carry out agricultural activities, many of the inhabitants migrated to the nearest urban centres to take unskilled jobs on construction sites. Since agriculture activities were limited to one or two periods instead of three full periods, access to wage work also was a grave problem in these areas. Another coping strategy, of note, was to borrow money from informal and formal sources to restore groundwater yield by deepening existing wells or drilling additional wells. In general, it should be noted that small farmers tended to adopt less capital intensive coping mechanisms as compared to larger farmer who were more inclined to implement more capital intensive measures.

VII. STRATEGIC IMPLICATIONS

Groundwater scarcity affects the livelihoods of rural communities in many different ways. It is, therefore, essential that communities implement measures that enable them to cope with the adverse effects of groundwater depletion. Policies and institutional innovations that are directed at strengthening the resource base of the rural agrarian economy must be developed. Specific measures that are relevant to the hard rock areas in coping with the problem of groundwater scarcity also need to be adopted.

First of all, farm households, in order to secure their livelihoods, need to adopt strategies at the household level. These strategies may include investments that will provide long-term benefits such as in education or other non-farm activities. This not only helps reduce pressure on the already degraded resource but builds strong resilience for the communities to take up future challenges.

Secondly, response strategies must entail activities that are less water focused, and are not directly related to groundwater where groundwater resources are under severe threat and conventional management strategies do not appear to be feasible. One alternative to consider, is low cost natural resource-based microenterprises that do not require high technology nor are closely linked to groundwater.

Third, from a hydrological perspective, identifying regions that are mostly likely to need support in putting in place livelihood and economic systems should be relatively straightforward. Timely information regarding the status of groundwater

resource availability must be made available to the groundwater users and concerned authorities should then suggest a suitable cropping pattern. This not only avoids putting stress on the resource base but also reduces the burden on farmers from crop losses.

Fourth, to effectively implement institutional reforms, a groundwater authority should be set up to oversee the process and make sure it does not stray from the overall objectives of resource management. The authority should carry out control and monitoring functions. Attention needs to be paid to the linkages between long-term groundwater management issues and short-term coping mechanisms. In this context, governments should promote the managed aquifer recharge (MAR) strategy developed by Andhra Pradesh Farmer Managed Groundwater Systems Project (2006). Under this strategy, institutions involving farmers play a key role in aquifer recharge as well as in reversing the trend of declining water levels. Thus, community participation must be encouraged in restoring aquifers and sustainable use of groundwater.

Finally, policy responses should focus on developing physical and social infrastructures that are relevant to the diversification of livelihoods. These infrastructures, which include, among others, roads, transport, financial institutions and, dairy development are important in helping members of farm households diversify their occupations and connect to the outside market.

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